Status of the Laser Risk Reduction Program at NASA Langley Research Center

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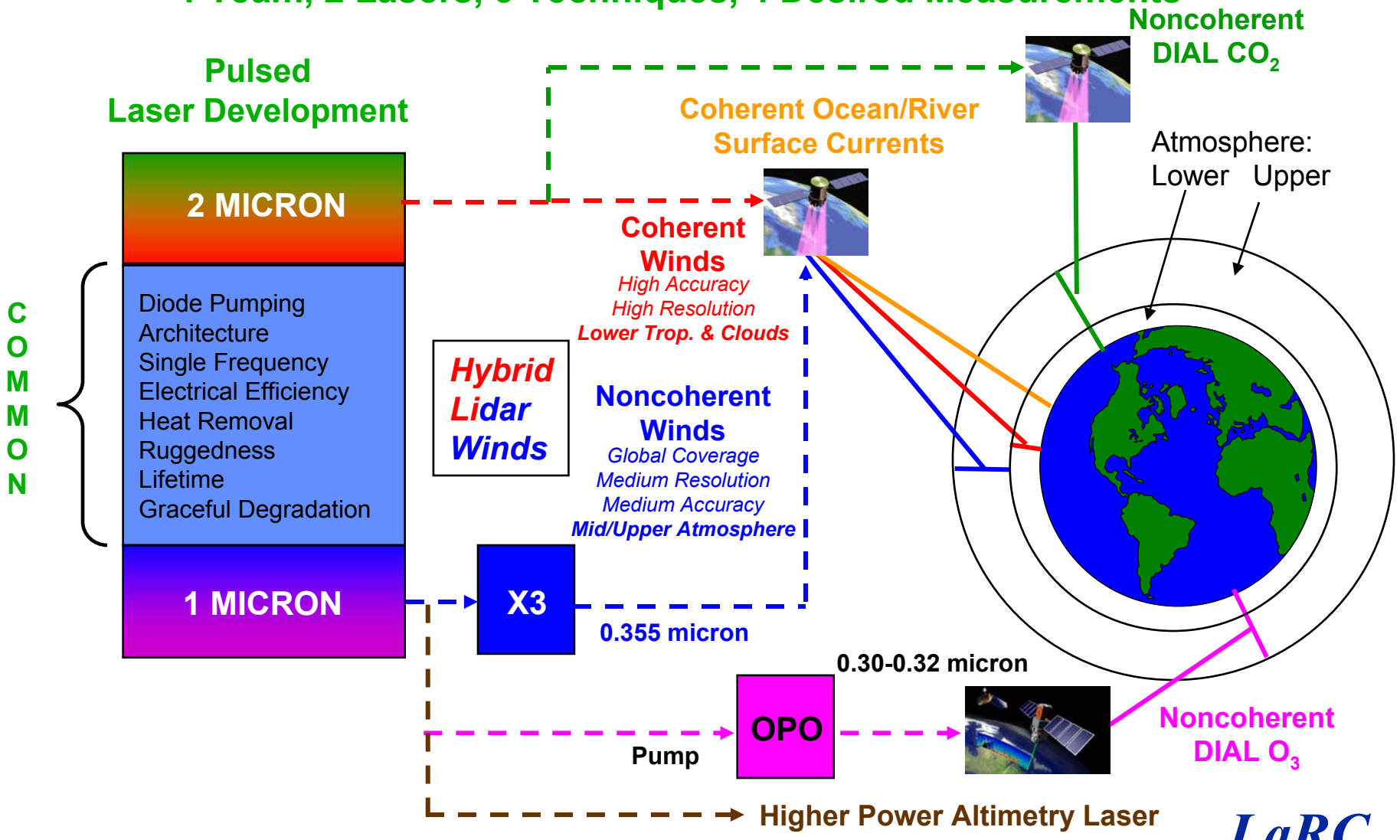
Program Origins

- In November 2000, the recommendations of the Independent Laser Review panel were published which included, amongst others, the creation of a “Space Laser Super Center” managed as a single organization at the NASA HQ level.
- In January 2001, a memo from the AA’s of Code Y and R requested that GSFC and LaRC jointly respond to three separate actions. These are quoted and listed in their order of appearance in the letter:
  - “and for GSFC and LaRC together to define the plans for working together on areas of mutual interest in laser development in a complementary way.”
  - “GSFC and LaRC must define how Centers will cooperate on future lidar competitive opportunities, in order to be able to fully participate in an integrated Agency research and development strategy for lidar technologies.”
  - Define “a GSFC/LaRC lidar working agreement as well as a description of your envisioned role in the Agency research and development strategy for lidar technologies/ Laser Development Steering Group.”
- LaRC and GSFC have formed a joint working team, the NASA Integrated Lidar Systems Strategy Team (NILSST), in response to these findings and requests.
- ESTO adopted the findings from these teams to create the Laser Risk Reduction Program. Funding began in FY02 with $2M each to GSFC and LaRC. In 2003, the Aerospace Technology Enterprise contributed $2.5M/year to each center in addition to ESTO’s contribution.

Integrated ESE Lidar Strategy

1 Team, 2 Lasers, 3 Techniques, 4 Desired Measurements



Laser Risk Reduction Program

2-micron Laser Transmitter Task

Develop high energy, high efficiency, conductively-cooled, 2-micron pulsed laser

Laser Diode Array Task

Establish capability to address the issues associated with diode laser array pumps for solid state lidar transmitters

UV Wavelength Conversion Task

Wavelength conversion technologies to convert laser pumps to efficient, high-energy, tunable, pulsed and CW lasers in UV and IR

Advanced 2-micron Detector Task

Advance detector technology for noncoherent (direct) detection DIAL lidar remote sensing near 2 microns wavelength

Advanced 2-micron Lidar Receiver Task

Integrated optical beam combination elements, photodetectors, RF amplifiers and electronics, and a 2-micron semiconductor diode laser local oscillator (LO).

2-micron Laser Transmitter

Objective

Develop a high-energy, high-efficiency, conductively-cooled, 2-micron pulsed laser.

Rationale/Applicability

2-micron applicable to trop winds and CO_2.

Description of Task

Develop a laser with conductively-cooled laser diodes; develop a thermal and optical simulation of the laser head; design and fabricate a fully conductively-cooled laser head; and design a compact, hardened laser.

Deliverables

Working laser with CC laser diodes; thermal/optical laser head simulation; bonding procedure knowledge; fully CC laser head.

2-micron Laser Transmitter

Accomplishments

1. Determined LuLF material as a more efficient laser crystal compared to the traditional YLF material. Experiments confirmed theoretical predictions that LuLF material enhances the laser performance by ~20% over that of YLF crystal.
2. Successfully demonstrated Ho:Tm:LuLF laser system with 1050 mJ Q-switched output energy.
   - The first time that a Q-switched 2-micron laser exceeds 1 J level
   - An order of magnitude higher energy than previously achieved by any other group
   - In the last 10 years, LaRC has advanced the energy from 20 mJ to 1 J
3. Completed the design and fabrication of a compact, injection-seed, conductive-cooled laser diode, liquid cooled laser rod oscillator. The performance of the laser system has been characterized and met expected theoretical results.
4. Incorporated the newly developed laser into a 2-micron pulsed Doppler lidar. This is the most energetic 2-micron diode-pumped laser ever incorporated in a complete Doppler lidar for wind measurements. Wind velocity was measured up to 11 km altitude including cloud targets, and up to 6 km not including clouds.
5. Completed optical, thermal and stress analysis, and mechanical design of a fully conductive cooled laser head. Fabrication is scheduled to be completed by end of summer, 2003.

These accomplishments are significant because notional space-based wind profiling measurement scenarios require pulse energies from 1 to 5 Joule. This accomplishment greatly lowers the credibility gap and risk for space missions using this laser technology

Laser Diode Array Task

Objective

Address issues associated with diode laser array pumps for solid state lidar transmitters. Ensure availability of laser diodes for pumping of efficient, solid-state lasers in future NASA missions

Rationale/Applicability

LDA's used in all solid-state lasers

Description of Task

- Develop laser diode requirements
- Conduct technical interchanges with LDA vendors and with DOD
- Procure initial selection of LDA's
- Perform initial LDA tests and analyses

Roles and Responsibilities

Diode lasers operating at 790-795 nm for pumping 2-micron lasers

Approach

- Define operational, physical, and environmental requirements
- Establish working relationships with Industry and DOD
- Collaborate and exchange data between GSFC and LaRC
- Provide input to laser diode manufacturers

Laser Diode Array Task

Accomplishments

Much of the activities under this task have been focused on the development of the Laser Diode Characterization/Lifetime Test Facility (LDCF) and investigation of advanced technologies leading to improvement of laser diode arrays operating at 792-nm wavelength. The LDCF consists of two measurement stations: Laser Diode Characterization Station and Lifetime Test Station.

- The assembly of the Lifetime Test Station of the LDCF continues with procurement of all the necessary components for simultaneous lifetime testing of 8 laser diode arrays complete and almost all the necessary parts delivered. A significant part of the control and data acquisition software was completed and installed on the main control computer to be tested.
- As part of the effort toward advancing the laser diode array technology, began the characterization of a custom-designed laser diode arrays with diamond substrate and heatsink. Preliminary measurements indicate a reduction of about 17% in thermal resistance for the diamond package. This is significant as it can translate to substantial increase in laser lifetime. Future plan includes simultaneous lifetime testing of the diamond package devices and the standard (BeO) array packages available commercially.

Wavelength Conversion Task

Objective

Develop wavelength conversion technologies to convert Nd:YAG laser into an efficient, high-energy, tunable, pulsed UV laser in the 305-308 nm and 315-320 nm wavelength ranges

Rationale/Applicability

305-320 nm used for ozone, techniques also relevant for direct detection winds (~355) and for water vapor (~944)

Description of Task

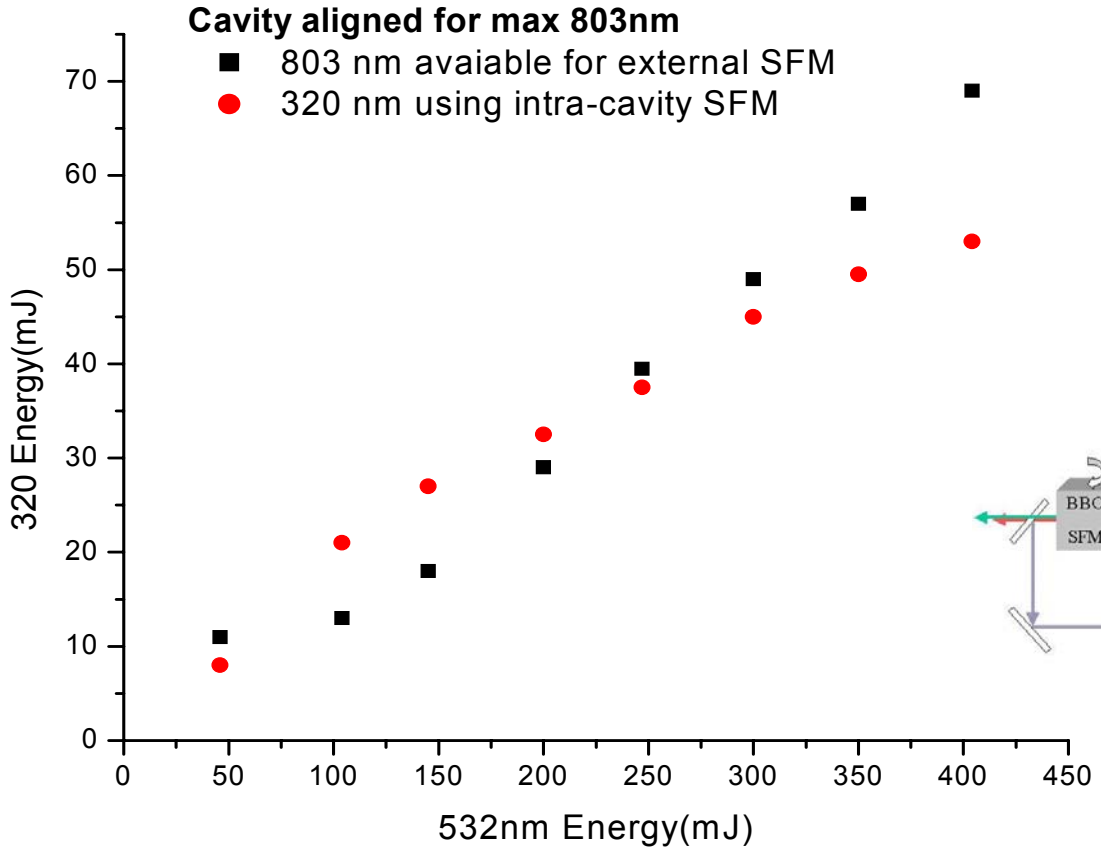
- Develop a high-power OPO/OPA/SFG at 320 nm
- Improve conversion efficiency
    - LaRC double pumped OPO
    - Sandia pulsed self-seeding OPO design

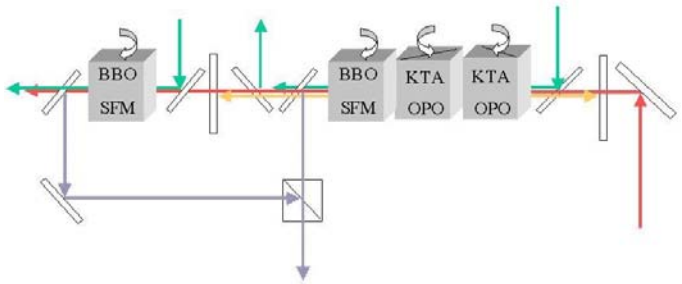
Deliverables

- 150 mJ OPO/OPA/SFG system
- Nonlinear optics to convert 1064 nm to 310 nm with 12% conversion efficiency

Wavelength Conversion Task

Accomplishments





Efficiency: 16.5% (532nm to 320nm) @ 103mJ
with 627 mJ of 532 nm

Advanced 2-micron Detector Task

Objective

The goal of this effort is to advance detector technology for noncoherent (direct) detection DIAL lidar remote sensing near 2 microns wavelength.

Rationale/Applicability

Improvements in detector technologies are critical to success of 2-micron lidar systems.

Description of Task

- Preparations are being made to accommodate various detectors in a cryogenic chamber so that single detector elements can be characterized at liquid nitrogen temperatures.

Status

- Two InGaAsSb detectors were recently obtained from AstroPower. Researchers performed characterization tests on these detectors including current vs. voltage (I-V), spectral response, and noise measurements. None of the detectors indicated an APD behavior as concluded from the I-V measurements. In addition to this, a wafer from Rochester Polytechnic Institute (RPI) was acquired and prepared for characterization. The wafer consists of several InGaSb photo detectors, with different areas. Also on the wafer are several pn diodes. Finally, researchers investigated the surface quality of the InGaSb substrate sample using an atomic force microscope (AFM).

Advanced 2-micron Lidar Task

Objective

There are two major activities under this task: Integrated Optical Heterodyne Receiver (IOHR), and Lightweight Scanning Lidar Telescope.

Rationale/Applicability

Improvements in lidar receiver technologies can mitigate the requirements for the lidar transmitter energy. Applicable to CO_2 and tropospheric winds measurements.

Description of Task

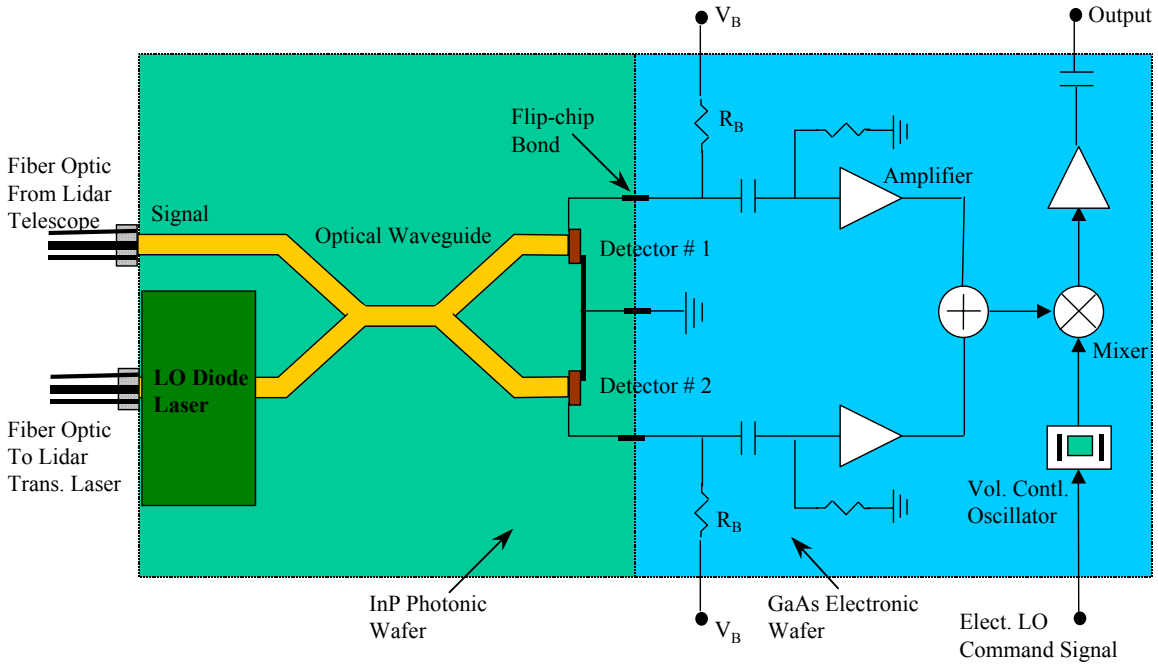
- IOHR combines optical and electronic components of a heterodyne lidar instrument into an integrated package less than a few cubic centimeters. The integrated components include optical beam combination elements, photodetectors, radio frequency amplifiers and electronics, and a 2-micron semiconductor diode laser that serves as the local oscillator (LO). Compared with a conventional lidar receiver, integration of these components will result in higher sensitivity, reduced size, and increased robustness when exposed to severe thermal and vibrational environments.

- The Lightweight Scanning Lidar Telescope (LSLT) concept is based on an athermal design using nickel shell optics and structure that is lightweight enough to be rotated about its axis for providing a step-stare conical scan pattern.

Advanced 2-micron Lidar Task

Status

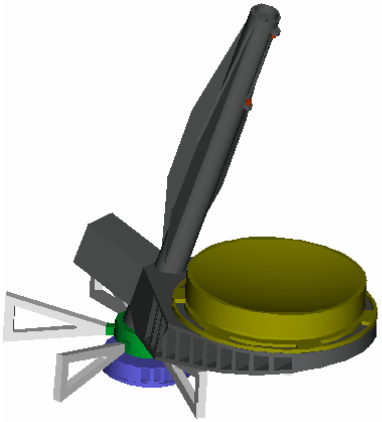
- A design for a Multi-Chip Module (MCM) Integrated Receiver has been revised to allow for more flexibility during laboratory experiments. The MCM receiver is based on dual balanced-detector architecture using a commercial SiGe Trans-impedance Die Amplifier. The new layout can be re-configured to allow characterization of individual components as well as implementing at least two different receiver designs.

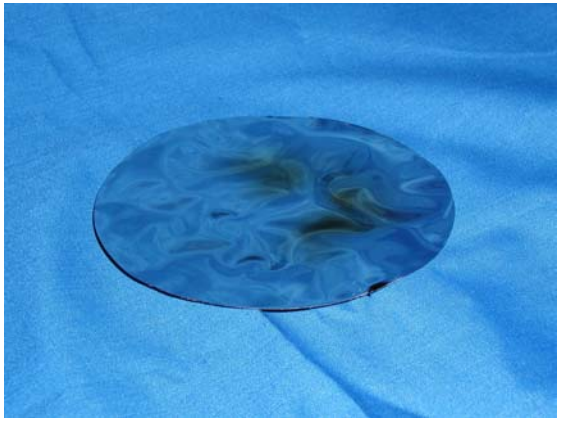


Advanced 2-micron Lidar Task

Status

- As part of the Lightweight Scanning Lidar Telescope activities, 3 aluminum mandrels were coated by nickel using an electroless plating process. The electroless coated mandrels will be then plasma sprayed to produce a thick nickel shell mirror. It is hoped that the nickel-coated mandrels will allow for a better separation than previously sprayed mandrels. Earlier plasma spray runs experienced bowing of the spray near the edges due to the tensile stresses. The nickel-coated mandrels are expected to allow for an easier release and better surface figure.
- Fabricated another nickel shell mirror pathfinder using the plasma spray technique. This latest piece, which is 10 cm in diameter, used an electroless nickel-coated mandrel instead of a bare aluminum mandrel or an aluminum oxide-coated mandrel. Shown in figure below, this mirror seems to be best part produced so far.





Future Plans

- Funding expected to continue in FY04, though funding contingent upon continued progress towards agreed upon milestones
- Technical Interchange Meetings between LaRC, GSFC and their collaborators will continue on a quarterly basis.
- Principal Investigators Upendra Singh (LaRC) and Bill Heaps (GSFC) will continue to lead tasks and be foci for program requirements

Recent Publications

A paper by Grady J. Koch, "Automatic laser frequency locking to gas absorption lines," Opt. Eng. 42(6), 1690-1693 (June 2003) was recently published.

The LaRC LRRP team presented several papers at the 2003 Conference on Lasers and Electro-Optics (CLEO), June 1-6, Baltimore, MD.

- J.A. Williams-Byrd, L.B. Petway, W.C. Edwards, M. Turner, "Room temperature laser performance of Nd:Y2O3 at 914 nm"
- N.P. Barnes, B.M. Walsh, and P.J. Thomas, "Relaxation Oscillation Suppression In Nd:YAG Laser Using Intra Resonator Harmonic Generation,"
- T.J. Axenson, N.P. Barnes, and D.J. Reichle, "Q-switched Diode Pumped Laser Comparison, Nd:GYAG Versus Nd:YAG At 0.946 microns,"
- M. Petros, J. Yu, G.J. Koch, B.M. Walsh, S. Chen, Y. Bai, U.N. Singh, and N.P. Barnes, "Double Pulsed High Energy Ho:Tm:LuLF Laser," CThM39
- Y. Bai, J. Yu, N.P. Barnes, M. Petros, S. Chen, "Intracavity Pumped Traveling-Wave Optical Parametric Oscillator," CTuM13
- J. Yu, H.R. Lee, N.P. Barnes, Y. Bai, K. Murray, "Tunable Infrared Radiation For Remote Sensing Applications," CTuM23
- S. Chen, J. Yu, U.N. Singh, M. Petros, Y. Bai, "A diode-pumped Tm:Ho:LuLF master-oscillator-power-amplifier (MOPA) at 2.05 microns", CThL3
- M.V. Pack, A.V. Smith, D.J. Armstrong, "The d Factory: a program to accurately measure d tensors of nonlinear crystals", CThU5

The team also presented the following papers at the 12th Coherent Laser Radar Conference, 15-21 June 2003, Bar Harbor, ME:

- B. Barnes, G.J. Koch, "Low Cost Coherent Doppler Lidar Data Acquisition and Processing"
- M.J. Kavaya, U.N. Singh, W.S. Heaps, T. Cazeau, "NASA's New Laser Risk Reduction Program for Future Space Lidar Missions"
- J. Yu, M. Petros, S. Chen, U.N. Singh, M.J. Kavaya, "High-energy 2-micron laser development"
- G. J. Koch, M. Petros, B. W. Barnes, J. Y. Beyon, F. Amzajerdian, J. Yu, M.J. Kavaya, U. N. Singh, "Validar: A Testbed for Advanced 2-micron Coherent Doppler Wind Lidar"
- G. J. Koch, M. Petros, J. Yu, J. Y. Beyon, B.W. Barnes, F. Amzajerdian, R. E. Davis, M. J. Kavaya, S. Ismail, U.N. Singh, "2-micron Coherent DIAL Measurements of Atmospheric CO2"
- F. Amzajerdian, B. Meadows, M. J. Kavaya, U.N. Singh, V. Sudesh, N. Baker, "High Power Laser Diode Arrays for 2-micron Solid State Coherent Lidar Applications"